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Overview of pest status, control strategies for *Spodoptera litura* (Fab.): a review

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ABSTRACT

The *Spodoptera litura* (Tobacco Caterpillar) has significantly damaged various cultivated crops, primarily affecting Solanaceous crops. It voraciously consumes the crop leaves, giving the appearance of animal grazing. It can cause extensive damage in its later stages, ultimately leading to crops decay. Commercial farmers typically depend on chemical pesticides for control. However, the overreliance on chemical insecticides to combat *S. litura* has led to the development of resistance over time. Various strategies have been explored in pursuit of environmentally friendly pest control measures. These include natural predators, employing techniques like sex pheromones and genetically modified crops, and utilizing RNA interference tools. While these methods have encountered implementation challenges, they are noteworthy for being safe, sustainable, and tailored to specific species. In this comprehensive review, we have delved into historical and current practices for pest management, covering cultural techniques, chemical controls, and biological methods. In addition, we have examined emerging technologies like the gene editing approach, nano-insecticides, neuropeptides and seminal fluid proteins that are promising tools in the ongoing efforts to manage *S. litura*.

Keywords: *Spodoptera litura*, Bio-pesticides, Polyphagous, Nano-insecticides, BT-Technology, Neuropeptides, Accessory gland Protein.

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INTRODUCTION

The global agriculture industry faces a significant challenge regarding loss of crop yield due to various abiotic and biotic factors, where insect pests play a substantial role in this decline. Insects have a wide variety of plant hosts, such as crops, weeds, and trees in forests, including ornamental plants. It can also infect packaged food products that have been kept in storage facilities, resulting in significant food loss and quality degradation. Insect pests are categorized as significant pests when they cause over 10% damage and minor pests when the damage ranges from 5% to 10% (Dhaliwal *et al.*, 2010). These insect pests collectively result in an 18–20% reduction in global crop production, where the annual loss of cost is around US $470 billion (Bihal *et al.*, 2023). Among these pests, the tobacco cutworm/caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae), is a significant polyphagous pest species. It is known to be a global pest causing substantial economic harm to various vital crops, including cotton, rice, tobacco, soybeans, vegetable and fruit crops (Srivastava *et al.*, 2018; Otuka *et al.*, 2020). It has been documented that *S. litura* larvae can feed on over 380 plant species (Wu *et al.*, 2019). The pest can potentially induce yield losses ranging from 35%

to 55% during crops' blossom and vegetative stages (Rao *et al.,* 2014). Many reports have mentioned the damage caused by this pest on vegetable crops like cabbage, cauliflower, brinjal, and turnip. Economically significant crops like cotton, tobacco, groundnut, soybean, sunflower, and castor are susceptible to damage caused by this pest (Suresh *et al.,* 2018; Ullah *et al.,* 2016). The larval feeding activities result in considerable economic losses for farmers, and the severity of these losses varies based on factors such as plant growth stage, crop type, and pest population density. In severe cases, yield losses can exceed 50%, leading to significant financial setbacks for farmers (Natikar and Balikai, 2015; Sharma *et al.*, 2022).

PROBLEMS RELATED TO *S. LITURA* MANAGEMENT

Spodoptera litura, has emerged as a highly destructive pest, with a wide profile of resistance to numerous insecticides, including endosulfan, cypermethrin, fenvalrate, and monocrotophos due to a long history of exposure as documented by Radhika and Subbaratnam (2006). Furthermore, the excessive reliance on insecticides to combat this pest has resulted in adverse consequences, including secondary environmental pollution; effective management demands a multifaceted approach (Srivastava *et al.,* 2018). Despite the extensive use of chemical insecticides, it's estimated that economic losses attributable to pests alone range from 20% to 30% (Kumar and Regupathy, 2000). Various management tools are recommended to mitigate the economic losses caused by pests, with insecticides being considered the last line of defense during severe infestations. This review emphasizes on *S. litura* as an insect pest, its host plants, the historical control methods, and innovative strategies for its future management.

LIFE CYCLE OF *S. LITURA*

Spodoptera litura goes through four developmental stages during its life cycle: egg, larva, pupa, and adult, similar to many other lepidopteran pests.

EGG

Ramaiah and Maheswari (2018), suggested that female moths typically deposit eggs in clusters within two to five days of their emergence. These newly laid eggs are round, slightly flattened, and have a pale orange-brown colour. They are arranged in patches, often with 1-3 layers, and are covered in brownish hair-like scales. These egg masses are approximately 4-7mm in diameter, and the colour of the eggs gradually darkens as they approach hatching. Latha *et al.* (2014) study revealed that egg incubation period extended from 4 to 5 days. Naturally, adult moths lay the eggs on leaves, and the side walls of the containers in the laboratory condition or on the muslin cloth.

LARVA

Upon hatching, the neonate larvae initially display a pale green hue, sporting a dark black head with prominently visible black hairs on the body. Additionally, a small black spot is distinctly observed on the first abdominal segment, which later transitions to a yellowish-green color. These larvae lack hair and exhibit dark and light longitudinal bands along their sides. Except for the prothorax, each segment's dorsal side features two dark semi-lunar spots positioned laterally. The lateral lines on the segments are interrupted, with the spots appearing notably larger on the first and eighth abdominal segments compared to the others. The *S. litura* larvae are mainly identified by the bright yellow stripe with various markings running along the dorsal surface. The hue of the larvae varies, with the early instars being light green and the later instars being dark green to brown. Before pupating, the adult larvae form a C-shape. Larvae go through five unique instars throughout the larval phase, which lasts between 13 and 15 days depending on the season (Cardona *et al.*, 2007).

PUPA

The pupae measure 15-20mm in length and display a color range from reddish to dark brown. They feature a broad and rounded anterior end, while the posterior end tapers to a pointed tip, which includes two small spines. To distinguish between male and female pupae, one can observe the spacing between the genital and anal pores. In female pupae, the genital pore is double the size of that in males. Moreover, female pupae exhibit a visible "V" shaped depression extending up to the tenth segment on either side of the genital pore. The pupal phase has duration of 7 to 8 days (Latha *et al.,* 2014).

ADULT

The moths are 15-20mm in length with a grey-brownish body. The forewings have a mosaic pattern and range in colour from grey to reddish-brown; the veins are lighter. Male moths are distinguished by dark grayish areas at the base and tip of their wings. In contrast, the adult moths exhibit a brown hue adorned with a complex pattern of creamy-colored crisscrossing markings on their forewings. A silvery-white color characterizes the hind wings. Male moths are notably more vibrant in color than their female counterparts, with a prominent white band on their forewings. Their thorax is covered with scales that are brightly colored. The adult females are bigger than the males and have a shorter abdomen, while the males exhibit brighter coloration compared to the female (Cardona *et al.,* 2007). The entire life cycle finishes within a span of 28 to 36 days (Figure 1).

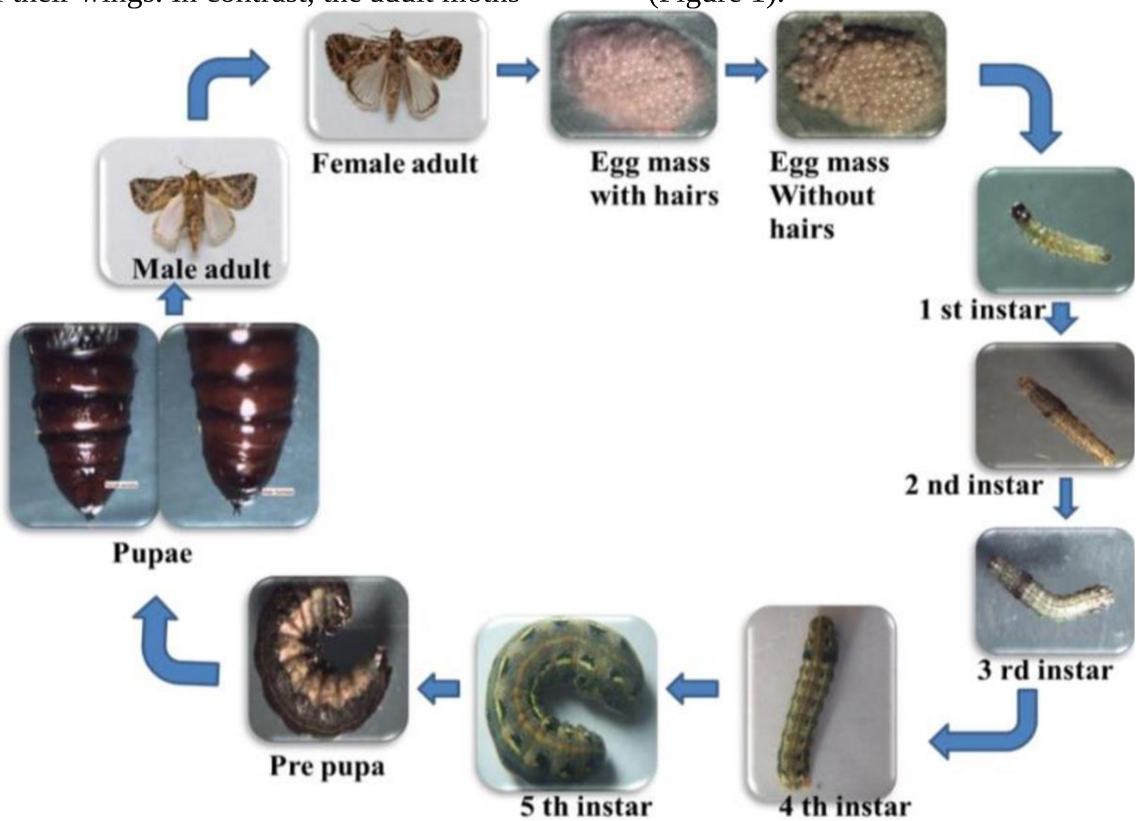

Figure1. The life cycle of *Spodotera litura* Source: Adopted from (Ramaiah and Maheshwori, 2018).

Global Distribution

The armyworm, recognized as a significant economic pest, is notorious for its attacks on various crops. It has a wide-ranging presence across the temperate as well as tropical regions of Asia, Australasia, and the Pacific Islands (Ahmad *et al.*, 2008). Originally native to India (Table 1) and Southeast Asia, it has also firmly established itself in Pakistan (Ahmad and Gull, 2017). This pest is a common threat in Indonesia and many other Asian nations and is also found in specific regions of Africa and Australia. Its distribution primarily covers tropical and temperate areas of Asia, the Pacific Islands, and Australasia (Feakin, 1973; Kranz *et al.,* 1977). Armyworm has spread to nearly all states in India, as illustrated in Table 1.

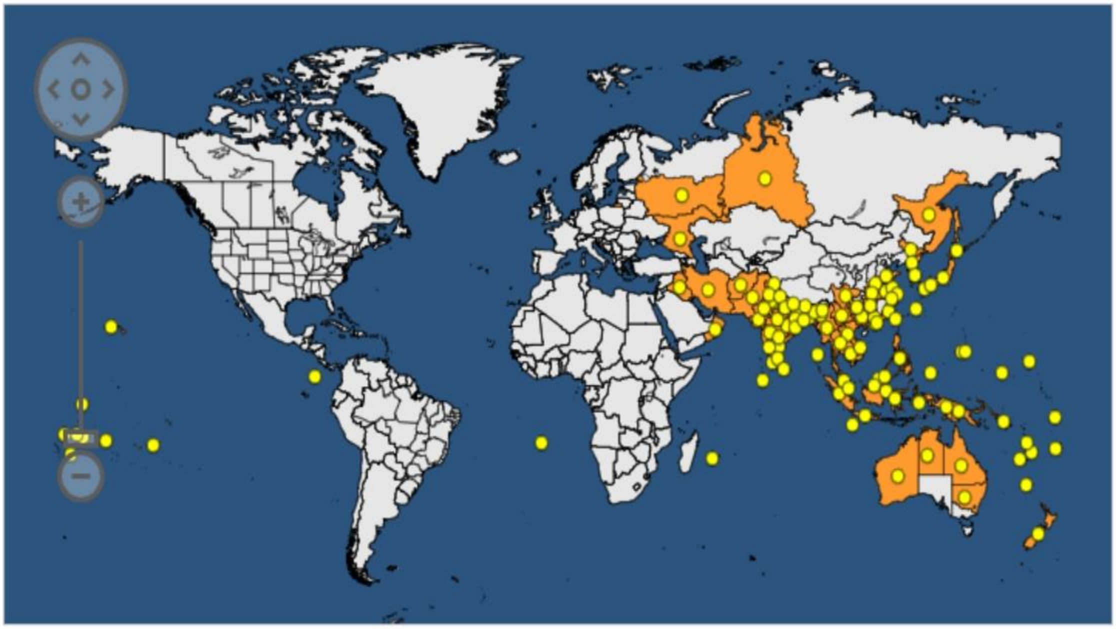

Figure 2. Global distribution of *Spodoptera litura* (extracted from the EPPO Global Database accessed on September, 2023)

A distribution map depicting the presence of this pest in various countries worldwide is provided (Figure 2).

HOST RANGE

According to CABI (Centre for Agriculture and Bioscience International) (2018), *Spodoptera litura* is known to be polyphagous, as indicated to feed on a minimum of 120 agriculture crops. These hosts span across a minimum of 40 flora families. Within the European Union, crops like beans (Phaseolus), Brassica species, eggplant (*Solanum melongena*), potatoes (*Solanum tuberosum*), tomatoes (*Solanum lycopersicum*), onion (*Allium cepa*), maize (*Zea mays*), rice (*Oryza sativa*), strawberry (Fragaria), sunflower (*Helianthus annuus*) and sugarbeet (*Beta vulgaris* var. *saccharifer*) are the main host plants. Additionally, citrus, grapevines (Vitis), and ornamental plants like roses (Rosa) are found to be the host species. However, the predominant host plants for *S. litura*, in Asian region, include beet (Beta vulgaris), chickpea (Cicer arietinum), cotton (Gossypium), groundnut (*Arachis hypogaea*), lucerne (*Medicago sativa*), maize, okra (*Abelmoschus esculentus*), rice, soybean (*Glycine max*), tea (*Camellia sinensis*), taro (*Colocasia esculenta*), tobacco (Nicotiana), and numerous other vegetable crops (Smith *et al.*, 1997; Gupta *et al.*, 2015).

PEST CONTROL STRATEGIES FOR *S. LITURA*

Numerous strategies have been implemented in the past and are currently in use, while many researchers are actively working on devising future approaches. The management of *Spodoptera litura* infestation and the damage it causes involve a combination of cultural, physical, chemical, and biological methods. The Integrated pest management (IPM) is a pivotal approach that employs biopesticides, secondary metabolites, natural predators, sex pheromones, and resistant crop varieties, among others. Recent strategies, such as genetically engineered (BT) crops, gene editing, nano-insecticides, RNA interference (RNAi), sterile insect techniques, neuropeptides, and seminal fluid proteins, hold significant promise in effectively controlling this pest.

Table 1. Distribution of *Spodoptera litura* in India

State	Distribution	Reference
Andaman and Nicobar Islands	Present	UK, 2014)
Andhra Pradesh	Present	Armes *et al. (* 1997)
Assam	Present	Das and Borgohain. 2019)
Bihar	Present	Kurly and Singh (2021)
Chhattisgarh	Present	Singh *et al. (* 2021)
Delhi	Present	Shankarganesh *et al. (* 2009)
Gujarat	Present	Gedia *et al. (* 2008)
Haryana	Present	Jeyakumar *et al. (* 2007)
Himachal Pradesh	Present	Sharma and Pathania (2014)
Jammu and Kashmir	Present	Ahmad *et al. (* 2011)
Jharkand	Present	Kurly and Singh (2021)
Karnataka	Present	Jha *et al. (* 2017)
Kerala	Present	Pattapu *et al. (* 2018)
Madhya Pradesh	Present	Sahu *et al. (* 2020)
Maharashtra	Present	Jadhav *et al. (* 2015)
Manipur	Present	Firake *et al. (* 2019)
Meghalaya	Present	Firake *et al. (* 2019)
Nagaland	Present	Sridhar *et al. (* 2016)
Odisha	Present	Sahoo *et al. (* 2014)
Punjab	Present	Kaur *et al. (* 2007)
Rajasthan	Present	Babu *et al. (* 2015)
Sikkim	Present	Firake *et al. (* 2019)
Tamil Nadu	Present	Kumar and Regupathy, 2001)
Telangana	Present	Duraimurugan, 2019)
Uttarakhand	Present	Joshi *et al. (* 2023)
Uttar Pradesh	Present	Reddy *et al. (* 2017)
West Bengal	Present	Kumar and Bhattacharya, 2019)

CULTURAL AND PHYSICAL PRACTICES

Manipulating the crop environment is a proven and practical approach to pest management for various cultivated crops. Standard methods of habitat manipulation include crop rotation, planting date, trap cropping, cover cropping, intercropping, *etc*. These strategies rely on natural enemies' hypothesis and resource concentration hypothesis for pest management that can help to keep the pest away from the main crop or increase the fitness of biocontrol agents for promoting conservation biological control (Tiwari *et al.*, 2020). Among these techniques, trap cropping stands out as a viable cultural method for pest control. Shekhawat *et al.* (2018) reported that the castor plants (*Ricinus communis*, Euphorbiaceae) used in cabbage and cauliflower fields can effectively safeguard the crops from *S. litura* infestations. Handpicking larvae is an economical and conventional approach to larval management. This method is primarily employed for larger insects and those that tend to feed in groups. It finds frequent use in dealing with caterpillars such as the tobacco caterpillar, fall armyworm, and hairy caterpillars (Sharma *et al.*, 2022).

CHEMICAL-BASED CONTROL METHOD

The most commonly adopted pest management practice among farmers involves repeatedly applying synthetic chemical insecticides. However, this approach is problematic because insect pests swiftly resist these insecticides. Consequently, the long-term use of insecticides is ineffective in pest management and escalates production costs. Additionally, synthetic chemicals threaten non-specific species including the ecosystem (Sharma *et al.*, 2020). For decades, chemical pesticides have been the cornerstone of agricultural strategies to combat pests and diseases in crop production. The FAOSTAT (Food and Agriculture Organization Corporate Statistical Database) reports that in 2019 to safeguard foods and its production, pesticides of about 4.15 million tons were used worldwide (FAOSTAT, 2021).

Nevertheless, the substantial increase in pesticide consumption has led to adverse consequences, with pest resistance emerging as a significant challenge in crop protection. It has shown resistance to organophosphates, pyrethroids, carbamates, chlorantraniliprole, abamectin, and benzene compound-related insecticides such as benzoate, bistrifluron, and indoxacarb (Gong *et al.*, 2021; Li et al., 2021; Shi *et al.*, 2021). This has necessitated the development of target-specific insecticides that can be used for effective resistance management strategies. Meeting by Central Insecticide Board and Registration Committee (CIBRC) in July 2021, released a list of approved pesticides and banned one for manufacturing use and import.

BIOLOGICAL CONTROL

Promoting environmental sustainability and enhancing human health are pivotal objectives attainable through adopting biological control methods as alternatives to harmful chemical pesticides. Bio-pesticides offer many advantages while minimizing adverse side effects (Thakur *et al.*, 2020). In contemporary agricultural practices, the central focus is on achieving sustainability, which involves harnessing the potential of organisms in the environment to enhance crop health, boost yields, and reduce pollution (Thakur *et al.*, 2022). Within this context, several well-established bio-control agents, such as bacteria, viruses, fungi, and entomopathogenic nematodes, present promising opportunities for effectively manage the population of *S. litura*. Modern agricultural practices prioritize sustainability as the primary objective. This is achieved by harnessing the potential of environmental organisms to enhance crop health, boost yields, and mitigate pollution, as highlighted in the work by Thakur *et al.* (2022). Along with microorganisms, natural enemies that act as predators, parasitoids, and entomopathogenic nematodes, stand out as promising contributors to effectively manage *Spodoptera litura* populations.

BACTERIA

Microorganisms can be used as definitive insect pathogens and, in this regard, many Bacillus species (Table 2) including *B. popilliae, B. lentimorbus, B. larvae, B. thuringiensis, B. sphaericus* are used as Microbial biological control agents (mBCAs) globally to manage pests (Charles *et al.*, 2000; Stahly *et al.*, 2015). Other microorganisms such as Serratia, Photorhabdus, Xenorahabdus, and Streptomyces so on are reported to be used as insect pathogens (Raymann *et al.*, 2018; Ruiu, 2015). Isolated microbes from the gut of adults *S. litura* such as *Enterococcus casseliflavus, Enterococcus mundtii, Serratia marcescens, Klebsiella pneumoniae, Pseudomonas paralactis* and *Pantoea brenneri* **are** subjected for investingion of insecticidal potential (Devi *et al*., 2022).

NUCLEAR POLYHYDROSIS VIRUS

Viruses of more than 450 are known to infect Diptera, Hymenoptera, and Lepidopteran insects. Among insect virus, Baculoviruses, are considered as safe and selective bio-insecticides, because of their species specificity. Commercial preparations of Nuclear Polyhydrosis Virus (NPV) (Table 2) based bio-pesticides, are used to control *Spodoptera litura, Spodoptera exiguva, Helicoverpa armigera,* and *Helicoverpa zea* that belong to Lepidopteran order.

Table 2. Natural enemies of *S .litura*

Type of Natural Enemies	Natural enemy species	References
	Predators	
Larvae Predators	*Rhynocoris marginatus*	Ullah *et al.* (2019)
	Rhynocoris fuscipes	Sahayaraj and Vinothkanna (2011)
	Rhynocoris kumarii	Sahayaraj *et al.* (2018)
	Zelus renardii	Petrakis and Moulet (2011)
	Parasitoids	
Egg parasitoid	*Telenomus remus*	Chen *et al.* (2022)
	Trichogramma chillonis	Shivankar *et al.* (2008)
Larvae parasitoids	*Campoletis chlorideae*	Bajpai *et al.* (2006)
	Eriborus argenteopilosus	
	Meteorus pulchricor	Nguyen *et al.* (2005)
	Apanteles colemani	Ramaiah and Maheswari (2018)
	Cotesia kazak	Walker *et al.* (2005)
	Bracon brevicornis	Ghosh *et al.* (2020)
	Cotesia glomerata	Ahuja *et al.* (2012)
Ectoparasitoid of moths	*Bracon hebetor*	Punia *et al.* (2021)
	Bactrial Pathogenes	
Larvae Pathogenes	*Bacillus thuringiensi*, *B. popilliae, B. lentimorbus, B. larvae, B. subtilis, Pseudomonas fluorescens Enterococcus casseliflavus, Enterococcus mundtii, Serratia marcescens, Klebsiella pneumoniae, Pseudomonas paralactis, Pantoea brenneri*	Natikar and Balikai (2015) Revathi *et al.* (2014), Charles *et al.* (2000), Stahly *et al.* (2015), Sahayaraj *et al.* (2018) Devi *et al.* (2022)
	Entomopathogenic fungi	
Larvae Pathogenes	*Aspergillus flavus* *Metarhizium anisopliae* *Paecilomyces variotii* *Beauveria bassiana* *Penicillium species* *Isaria fumosorosea* *Metarhizium anisopliae*	Kaur *et al.* (2020) Sarwar (2017) Tomar *et al.* (2022c) Ullah *et al.* (2019) Arunthirumeni *et al.* (2023) Vinayaga *et al.* (2015) Sahayaraj *et al.* (2018)
Larvae Pathogenes	Virus Granulosis Virus *Spodoptera litura* Nuclear Polyhedrosis Virus NPV *Baculovirus*	Gupta *et al.* (2015) Ayyub *et al.* (2019) Shaurub *et al.* (2014)
	Entomopathogenic Nematodes	
Pathogenic of Larvae	*Steinernema siamkayai* *S. carpocapsae* *Heterorhabditis bacteriophora*	Burana *et al.* (2022) Thakur *et al.* (2023)

Delivery of NPV along with neem seed kernel extract as well with the combination of endosulfan against *S. litura* indicated the reduction of the larval population in a field study (Kumar and Singh, 2009). Another study on *S. litura* revealed high larval mortality with NPV in combination of thianocotinyl, a chitin synthesis inhibitor, diflubenzuron and (chloronicotinyl) (Trang and Chaudhari, 2002).

PREDATORS AND PARASITOIDS

An eco-friendly way of managing insect pests includes predators and parasitoids because of their role as enemies in nature. Various bird species, including sparrows, starlings, and swallows, feed on *Spodoptera litura* larvae and pupae. Ladybugs, lacewings, and certain ground beetles are insect predators that consume *Spodoptera litura* at various life stages. *Platymeris laevicollis* (Distant), *Zelus renardii Kolenati, Rhynocoris marginatus* (Fab.), *Rhynocoris fuscipes* (Fab.) and *Rhynocoris kumarii* (**Table 2)** (Sahayaraj, 2014; Petrakis and Moulet, 2011) are few examples of predators of *Spodoptera litura*. Similarly, Trichogramma wasps parasitize *Spodoptera litura* eggs by laying them inside, preventing the eggs from hatching and reducing the population. In this way, the natural enemies make valuable components of integrated pest management (IPM) programs.

ENTOMO-PATHOGENIC FUNGI

Entomopathogenic fungi (EPF) are well-suited to meet the growing demand for eco-friendly pest management, as their infective propagules can bring about disease in pest insects with just direct contact. These microorganisms possess the unique ability to infect, parasitize, and ultimately eliminate arthropod pests. Because of these characteristics they are used in organic farming as an alternative to chemical pesticides and have also found applications in biotechnological processes and conventional Chinese medicine (Bihal *et al.*, 2023). The EPF encompasses a diverse group of over 500 species known for their capacity to parasitize insects, offering a sustainable approach to pest control.

In a recent study, Jamunarani *et al.* (2022) used indigenous *Beauveria bassiana* as a biocontrol agent for *S. litura*. Meanwhile, Tomar *et al.* (2022c) evaluated the impact of an entomopathogen, *B. bassiana,* on Spodoptera larvae. They reported its effectiveness in managing the insect population in laboratory and greenhouse conditions. Impact of plant secondary metabolites from *Isaria fumosorosea*, *Beauveria bassiana*, and *Paecilomyces variotii* **(**Table 2) have been studied on various aspects of *S. litura*, including fecundity, hatchability, growth, and feeding activity. Penicillium species producing secondary metabolites have been studied to control *S. litura* larvae (Arunthirumeni *et al.*, 2023). Solvent extracts of these metabolites resulted in significant impact on the pest's fecundity and hatchability (Vinayaga Moorthi *et al.*, 2015).

ENTOMOPATHOGENIC NEMATODES (EPNS)

The EPNs are used as biological control agents targeting a wide range of foliage and hidden insects. Tomar *et al.* (2022b) demonstrated that Entomopathogenic Nematodes (EPNs) are highly effective in managing insect populations in controlled poly-house environments and open field conditions. Two commercially available EPN strains, *Steinernema siamkayai*, and *S. carpocapsae*, because of their virulence had a positive impact on various developmental stages of *S. litura* larvae. First and third larval instars showed mortality to *S. siamkayai*, while *S. carpocapsae* (**Table 2)** caused higher mortality in older larvae (Burana *et al.*, 2022). According to Thakur *et al.* (2023) research, the *Heterorhabditis bacteriophora* EUPT-SD resulted in a 100% larval mortality rate at the highest concentration when used against *S. litura* larvae. Utilizing these pathogens is environmentally friendly and is an effective alternative to synthetic chemical insecticides.

BOTANICAL EXTRACTS

Botanical extracts have gained increasing attention as a viable option for assessing current and future pest control alternatives. They possess the advantages of being biodegradable environmentally friendly, and thus used in Integrated Pest Management (IPM) programs. Plant extracts, which contain secondary metabolites sourced from various parts of plants, are employed in pest control. Many plant species found in tropical regions are renowned for their pesticide properties and their eco-friendly, cost-effective, and non-toxic characteristics, making them a preferable choice over chemical pesticides. Neem (*Azadirachta indica*), for example, has been the subject of numerous studies, with several demonstrating its effectiveness against a wide range of pests. The compounds within neem exhibit various activities against insects, including acting as anti-feedants, growth inhibitors, regulators of growth, reducers of fecundity, inducers of sterility, and protein synthesis inhibitors. These effects are observed in a broad spectrum of insect groups, including Lepidoptera (Vollinger and Schmutterer, 2002).

Synergistic effect of 1, 8-cineole has been found to inhibit AChE on interaction with octopamine (GABA receptors) (Zhukovskaya, 2007; Abdelgaleil *et al.,* 2009). Furthermore, Janku *et al.* (2012) explained that many of the botanical species are rich in saponins, that they act as natural surfactants in pesticide adjuvants (cake-shaped oil-tea camellia dregs, pod skin of the Chinese honey locust, and soapberry fruit). Along with specific plant essential oils (bark) of cinnamon, lemongrass, and rosemary have been used as natural repellents and adjuvants against mosquitoes (Sheng *et al.,* 2020; Norris and Bloomquist, 2021). The diverse array of activities displayed by many plants secondary metabolites against various insect species makes these botanical compounds a valuable resource in developing pesticides. Most of the plants active ingredients exhibit slow-acting activities by impeding larval growth and interrupting insect development and few exhibit toxicities by killing the larvae (Ikbal and Pavela, 2019; Isman, 2020). In a recent study, Cui *et al.* (2022) reported synergistic effects of curcumin, a natural polyphenol, in combination with avermectin against *Spodoptera litura*. Another report by Yooboon *et al.* (2019) identified the potent efficacy of ethanolic crude extracts from various

plant sources, including *A. calamus*, *A. galangal*, *C. longa*, *P. nigrum*, *P. retrofractum*, and *S. trilobata*, in controlling the *S. litura*. They also suggested that *P. retrofractum* and *A. calamus* extracts are effective pesticidal compounds for managing *S. litura*.

SEX PHEROMONES

Sexual pheromones are pivotal in triggering mating behaviors in moths. Disrupting mating offers a promising avenue for controlling pests. Therefore, as a strategy for the prevention of mating behavior, understanding the sex pheromone production and the factors influencing it is crucial. Alternatively, synthetic sex pheromone traps are produced for pest control. Tamaki *et al.* (1973) isolated and characterized the primary constituents of S. litura sex pheromones known to be (Z9, E11)-tetradecadienyl acetate (Z9, E11-14: Ac) and (Z9, E12)-tetradecadienyl acetate (Z9, E12-14: Ac).

Synthetic sex pheromones have been utilized as traps to manipulate the population density of *S.litura* in agricultural settings is a straightforward and effective strategy adopted across various cropping systems (Shih *et al.,* 1995; Yang *et al.,* 2009). Nevertheless, the mass trapping and extermination of pests rely on the obtainability of the attractant and are only suitable for known pests. However, the main barriers to technology adoption are its high cost, labor-intensive nature, topographical problems, and efficiency-eroding edge effects (Witzgall *et al.,* 2010).

INTEGRATED PEST MANAGEMENT (IPM)

Pest control strategy with the help of Integrated Pest Management (IPM) is a systems approach, considering the entire agricultural ecology. This approach involves a deep understanding of how pests interact with their host plants, the prevailing climatic conditions, plant health, nutrition, and interactions. A combination of tactics, such as physical and mechanical barriers, pruning, pinching practices, using sex pheromones, and biological control, should be employed sustainably and with cost-effectiveness while minimizing environmental and human risks (Bateman *et al.,* 2018). As the loss incurred by the pest is more,

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farmers resort to the use of chemicals though Integrated Pest Management (IPM) stands out as the most effective and preferred method for *S. litura* management. However, in regions like Nepal, where the pest's incidence is on the rise, IPM represents the most suitable and effective approach for pest control (Day *et al.*, 2017). Various researchers have devised distinct modules for managing *S. litura*. Koppenhofer and Kaya (2000) documented that the combination of neem seed kernel extract and NPV treatment demonstrated heightened suppression of overall activity in multiple aspects, attributed to decreased fecundity, feeding, larval weight, survival, and growth rate of Lepidoptera.

GENETIC BASED METHOD

New studies concentrating on insect target locations have been conducted in conjunction with the considerable advancements in molecular biology. Together with other microbial species, *Bacillus thuringiensis* (Bt) is a successful example of both industrial and academic spheres. This spore-forming bacterium is ubiquitous and produces crystal proteins, also known as δ-endotoxins, which can be directly integrated into plants through genetic engineering (Thakur *et al.*, 2022). Utilization of Bt toxin to control pest infestations is an alternative approach to chemical pesticides. However, a significant concern associated with this technology is the reduced susceptibility of pests to Bt toxins (Gould, 1998). The Cry toxins produced by Bt are currently extensively recognized as biocontrol agents (Yinghua *et al.*, 2017; Afriani *et al.*, 2018). Recently, Song *et al.* (2018) have detected the transcriptional response of *Spodoptera litura* larvae to Vip3Aa toxin, a new group of insecticidal toxins produced by *B. thuringiensis* and established its effectiveness in their report. Nevertheless, the rapid emergence of resistance to Cry toxins by insect populations and the reduction in toxin content in aging plants (Heckel *et al.*, 2007; Olsen *et al.*, 2005) have necessitated the exploration of alternative eco-friendly strategies to combat pest infestations in agricultural fields.

It has been reported that the few insects have shown resistance against target species of insects due to extensive adaption of Bt technology, predominantly in regions with warmer environmental conditions (Gassmann *et al.*, 2009; Carriere *et al.*, 2010; Tabashnik *et al.*, 2013; Tabashnik and Carrière, 2017). Research has shown that some Lepidoptera pests have already developed resistance to Bt toxins, as observed in cases of Fall armyworm (Storer *et al.*, 2010; Huang *et al.*, 2014; Farias *et al.*, 2014; Omoto *et al.*, 2016), and Cotton bollworm (Candas, 2003) and so forth.

GENE EDITING APPROACH (CRISPR-CAS SYSTEM)

CRISPR/Cas9 technology one among the valuable tool of gene editing technology has provided researchers with resistance mechanisms that could be used as novel pest control strategies (Books, 2019). Wu (2020) elucidated the effective use of CRISPR/Cas9 technology for deleting the abdominal-A homeotic gene in the *Spodoptera frugiperda*, suggesting its high efficiency in editing the *S. frugiperda* genome. In this pest, CRISPR/Cas9-mediated site-specific mutagenesis was applied to mainly three target genes: two marker genes: biogenesis of lysosome-related organelles complex 1 subunit 2 (BLOS2) and tryptophan 2,3-dioxygenase (TO) and a developmental gene, E93, which is a pivotal ecdysone-induced transcription factor promoting the development of an adult. The findings from this mutational research underscore the necessity to enhance genome editing techniques in specific lepidopteran and also non-model insects, potentially through alternative tactics (Zhu *et al.*, 2020).

NANO-INSECTICIDES

The potential of nanotechnology holds the promise of bringing about significant transformations in the agricultural industry. Insect pest management using nanoparticle-based insecticides is one of the recent trends in *S. liture*. When *Trichoderma viride*-mediated nanoparticles (insecticides) were applied at a concentration of 100ppm, they showed complete anti-feedant activity on *Helicoverpa* *armigera* larvae. Subsequent exposure to these synthesized nanoparticles upregulated the Glutathione-S-transferase activity while down-regulating the glucosidase in the *H. armigera* third-instar larvae (Bihal *et al.,* 2023). Furthermore, a separate study by Karthick *et al.* (2021) revealed that fungal metabolites capped silver nanoparticles exhibited significant mortality of *S. litura*. Thakur *et al.* (2022) reported, the insecticidal effectiveness of Zinc oxide nanoparticles (ZnO NPs) synthesized with Ginger rhizome extract (*Zingiber officinale*) indicated 100% mortality in third-instar larvae of *S. litura*.

RNA INTERFERENCE TECHNOLOGY

Another powerful method for managing pests, RNA interference (RNAi) is a potential method for quickly examining gene activity and is seen as the future of insect pest control as highlighted by Gong *et al.* in (2012). The initial successful application of RNAi took place in the cecropia moth *Hyalophora cecropia*, a milestone described by Bettencourt *et al.* (2002). In their review, Xu *et al.* (2016) observe the utilization of RNAi experiments across various adult species, focusing on functional gene analysis and agriculture pest management investigation. In the case of *Spodoptera litura*, RNAi has been employed to silence genes such as olfactory receptors (Zhang *et al.,* 2016), catalase (Zhao *et al.,* 2013), sex-peptide receptor (Li *et al.,* 2014), and pheromone biosynthesis activating neuropeptide (PBAN) (Lu *et al.,* 2015).

A recent study by Yang *et al.* (2023) delved into the potential roles of SlitPer in sex pheromone association in *S. litura*, utilizing RNA interference and molecular techniques. This investigation included behavioral assays, such as calling, mating, and oviposition. Nonetheless, several limitations are associated with using RNAi-based technology for pest control, particularly the challenges of identifying suitable target genes and an effective delivery method.

STERILE INSECT TECHNIQUE

Employing pest control strategies like the sterile insect technique (SIT) and inherited sterility (IS) is both environmentally friendly and highly effective when managing *S. litura* pests. This approach involves the cost-effective targeting of operations, ensuring the separation of male and female insects based on their sex, the sterilization of male insects using ionizing radiation, and the subsequent release of these radio-sterilized males in the designated area (Dyck *et al.*, 2021). The study conducted by Sengupta and colleagues in 2023 demonstrated the impact of radiation on the expression of the PBAN gene (responsible for triggering pheromone production) in irradiated female *S. litura*. As a result, irradiated moths exhibited significantly reduced PBAN expression during both the photophase and scotophase compared to the control group. However, it's important to note that while SIT has demonstrated success in managing dipteran pests, its efficiency in eradicating lepidopteran pests has been less pronounced (Sengupta *et al.,* 2023).

NEUROPEPTIDES BASED METHOD

Currently, there is a total of 4782 neuropeptides, each serving various physiological roles. This extensive list opens up possibilities for developing innovative pest control agents structured as backbone cyclic (BBC) peptidomimetic antagonists targeting insect own neuropeptides. Some of well-known neuropeptide classes such as PBAN, allatostatin, proctolin, and kinin, have been successfully characterized. Building upon these sequences, researchers have synthesized peptidomimetic analogs, which can function as agonists or antagonists. These synthetic compounds were artificially synthesized and evaluated for their insecticides activity (Elakkiya *et al.,* 2019). Allatotropin, belonging to the family of myoactive neuropeptides establish in various invertebrates, is responsible for stimulating the biosynthesis of juvenile hormone (JH) in corpora allata (CA) (Elekonich and Horodyski, 2003).

Numerous reports have indicated the pivotal role of Juvenile hormones in various developmental and reproductive processes in insects, encompassing embryogenesis, larval molting, metamorphosis, vitellogenin synthesis, vitellogenin uptake by the ovaries, ovarian development, spermatogenesis, and accessory glands development (Gade *et al*., 1997; Koeppe *et al*., 1985; Riddiford, 1994). The PBAN, known to be a neuropeptide consisting of 33 amino acids with a C-terminal amidation, is known as Hez-PBAN. It is generally accepted that PBAN plays a significant role in regulating pheromone production in many lepidopteran species, including the *S. litura* (Lu *et al*., 2015; Choi *et al*., 2012; Chang, 2014; Abernathy *et al*., 1995; Fabrias *et al*., 1994; Matsumoto *et al*., 1995). In a recent study, Mamtha *et al*. (2021) identified the presence of allatotropin, a neuropeptide, within the male accessory gland of *Spodoptera litura*. The recombinant allatotropin (neuropeptide) stimulates egg-laying in female moths. Any disruptions in the neuropeptide expression and regulation could lead to alterations in insects' physiology and behavioral aspects. Thus, a comprehensive exploration of neuropeptides, including their fundamental structure, functions, and mechanisms of action, is essential in the development of potential targets for pest control.

SEMINAL FLUID PROTEINS/ MALE ACCESSORY GLAND PROTEINS (MAGS)

Seminal fluid proteins (Sfp) in numerous insect species are transferred to females during mating, accompanied by sperm. These transferred Sfp can alter female behaviour and exert control over her reproductive activities. Both in terms of quantity and significance in influencing female reproductive processes, the primary constituents of secretions are known to be proteins (Saraswathi *et al*., 2020). The initial discovery of a protein called 'sex peptide' or accessory gland protein 70A (Acp70A) in *Drosophila melanogaster*, identified by Chen et al. in 1988, demonstrated its capacity to enhance egg-laying and reduce female receptivity.

In *Helicoverpa armigera* similar effects have been observed for oogenesis and Oviposition factors (OOSF) (Jin and Gong, 2001). Researchers have extensively utilized proteomic and transcriptomic techniques, in conjunction with bioinformatics analysis, to identify and characterize several male accessory gland proteins in *Callosobruchus maculatus*, (Bayram *et al*., 2019), *Helicoverpa armigera* (Chaitra *et al*., 2020), *Leucinodes orbonalis* (Saraswathi *et al*., 2021), and *Bactrocera dorsalis* (Wei *et al*., 2015), So on. From the perspective of *S. litura*, Mamtha, *et al*. (2019) discovered 566 proteins in male accessory glands (MAGs) from both virgin and mated individuals, and they observed 91 proteins that exhibited differential expression following mating. Twenty spots were sequenced using MALDI-TOF/MS. This revealed the presence of proteins like desaturases, glutathione S-transferase, hydrolases, transferases, cytochrome P450, heat shock proteins, putative chemosensory protein, odorant receptor, poly ADP- ribose polymerase, bloom syndrome protein homolog, spastin and flap endonuclease. The author also proposed that these proteins play essential roles in oogenesis, long-term sperm storage, fertilization, sex pheromone production, and protein folding.

Additionally, the continuation of the Next Generation (NGS) sequence profile of MAGs of *S. litura* yielded a total of 91,744 unigenes that were predicted. Further with the help of the bioinformatics tool the highly significant genes were identified, such as odorant binding proteins, heat shock proteins, juvenile hormone binding proteins, carboxypeptidases, cytochrome P450 enzyme, and serine proteases (Mamtha *et al*., 2023). The explained studies collectively demonstrate the transfer of peptides from males to females, suggesting their potential involvement in female reproduction. Identifying proteins/peptides with the capacity to control pest populations represents a promising technology for the future, offering the possibility of producing safe, specific, and environmentally friendly bio-pesticides.

Spodoptera litura, commonly known as the tobacco caterpillar, is a highly significant polyphagous pest that causes substantial agricultural losses worldwide. This review delves into various aspects of the tobacco caterpillar, including its pest status, distribution, biology, capacity for damage, economic losses, seasonal occurrence, host range, and ecological interactions. This pest poses a formidable menace to a wide variety of crops, encompassing cotton, corn, tobacco, and diverse vegetables. The development of effective management strategies is imperative to safeguard crop yields and mitigate economic setbacks. Historically, attempts have been made to control this infestation, but the success rate using traditional methods has been relatively low when compared to modern approaches. In conclusion, the management of *S. litura* demands a comprehensive and integrated approach that incorporates both chemical and non-chemical methods. Prioritizing sustainable, environmentally friendly, and economically viable strategies is crucial to ensure the long-term sustainability of agricultural ecosystems and food production. Continuous research and adaptability in management strategies are vital to keep pace with evolving pest populations and mitigate the impact of *S. litura* on global food security.

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Statement of Author Contribution

Every author made an equal contribution.

Conflict of Interest

There isn't one.

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